Despite continual advances in the development of chemotherapeutic agents since the discovery of penicillin by Fleming in 1928 and its first successful applications in clinical practice in the early 1940s, microbes have continued to evolve and pose a challenge to clinicians. Skin and muscle infections, osteomyelitis, septic arthritis, and implant-related and prosthetic joint infections make up this group of ailments. The incidence of such infections is increasing as more orthopaedic surgical procedures are being performed, life expectancy is increasing, and urbanization and the rise in motor vehicles use in third-world countries are creating more opportunities for traumatic injuries. It is imperative that orthopaedic surgeons understand how microbes colonize and live in a host, as well as current modalities for treating bone and soft-tissue infections. This chapter focuses on the pathophysiology of microbial infections and new treatment trends for bone and accompanying soft-tissue infections.

The premise of dealing with infections rests on the fact that there is a continual battle between the prokaryotic and eukaryotic cells that make up humans. Although it is tempting to think of humans as eukaryotic organisms, eukaryotic cells in humans are outnumbered 10:1 by prokaryotic cells in individual biospheres. Humans must...
live in some type of homeostasis with the very microbes that can lead to their demise via uncontrolled infection.

Pathophysiology of Bone Infections

To understand how a deep infection takes hold in the body, several key terms must be understood. Biofilm represents the microenvironment created on a surface by microbes in the body. Biofilm can occur on bone, tendon, muscle, or any dysvascular or devascularized structure or on foreign-implanted structures such as plates, rods, or prosthetic joints. Biofilm represents a highly organized polymeric matrix of cellular debris, including DNA, proteins, and polysaccharides. In essence, this debris represents the organized cell death of the invading microbes after colonization and adherence to a site. As the microbes in the “first line of attack” perish, a scaffold is left that forms a matrix for the construction of the biofilm microenvironment by the next wave of microbes.

The planktonic cell phase in a microbial cell cycle represents the cells that are commonly attributed to infection. These cells represent the initial inoculum at the site of an infection. They are young cells and have a rapid turnover. These cells float freely in a wound or the bloodstream (hence the term planktonic) and have a high metabolic rate and a rapid generational cycle (20 to 30 minutes in many bacterial species). The planktonic cells are the initial infecting form of an organism. This cell line is particularly sensitive to antibiotics.

In the sessile cell phase, the microbes convert to a slow metabolic rate and a slow growth cycle. This phase occurs when the microbes have colonized and are “hiding” in the established biofilm. The microbes are not in spore form but rather are almost in a hibernation-like state. The generational cycle of the microbes is hours to 1 day.

This information is useful in understanding how chronic colonization and infection of bone and implants occurs over time. After the initial invasion to the nidus, the process of reversible adsorption of the microbe to the surface occurs. This process takes seconds to minutes. With time and a suitable nidus, the process of irreversible attachment occurs. This leads to growth and division of the organism at the site of the infection and lasts for hours to (more often) days. During this time, the organized cell death of the first wave of microbial attackers occurs.

During the ensuing days, the exoskeleton of a biofilm is manufactured from the initial outlay of prokaryotic cell debris. In wounds and in the oral cavity, this initial wave of cell death often can be polymicrobial, which will assume some importance later because this represents a pool of DNA in the matrix. With time, the biofilm becomes a fully matured and organized biosphere for the colony. It is not known how long it takes for a mature biofilm to develop from the time of the initial inoculum.

With the establishment of a mature biofilm, the cells enter into the sessile phase. This phase poses a substantial barrier to combating the infection for four reasons. (1) The highly structured hydrophobic nature of the biofilm complex creates a semi-impermeable barrier to antibiotic access to the microbes, with very slow penetration of the antibacterial agents into the biofilm (Figure 1). (2) The microbes hide in the primordial sludge of the biofilm; this offers protection from an administered antibiotic (Figure 2). (3) Because the microbes are living in a sessile phase with a slow metabolic rate, they are, on average, $10^3$ times less sensitive to most currently available antibiotics. This is especially true for the many antibiotics in clinical use that work by altering or inhibiting cell wall synthesis. (4) An enriched subpopulation of a cell phenotype has been isolated in mature biofilms. This microbial cell line is called persister cells. These are not a mutant cell line because they possess the same genome as the colony population. The persister cells exist in a dormant (but reversible) state that renders them insensitive to antimicrobial agents that would normally kill a genetically identical microbial colony. In a mature biofilm, persister cells typically represent approximately 1% of the cell population. It is important to distinguish that these cell lines are not composed of antibiotic-resistant cells because this would imply genetic mutations or horizontal gene transfer. The persister cells offer a pool of fresh cells that are multidrug tolerant and can continually repopulate the biofilm colony. Although first described in 1944, the important role of persister cells in biofilm tenacity has not been appreciated until recently. These four reasons make biofilms a formidable challenge in treating bone and implant-related infections. The time from inoculation to the development of a mature biofilm that is impenetrable to systemic antibiotics has not yet been determined.

The term distributed genome hypothesis has been used to describe an additional confounding factor in a host’s difficulty in combatting biofilms. As previously mentioned, the
Advances in the Understanding and Treatment of Musculoskeletal Infections

Chapter 4

© 2015 AAOS Instructional Course Lectures, Volume 64

39

initial inoculum of an infection often can be polymicrobial, with multiple species and multiple strains of a single species. During the first wave of an attack, with the dead cells serving as a substrate for biofilm formation, DNA from dead microbes is present in the milieu. This pool of DNA represents a potential supragenome from which the colony can transform via real-time horizontal gene transfer. The distributed genome poses another potential impediment to the host in its attempt to eradicate the biofilm.

Antibiotics work well against microbial growth in the planktonic phase but are far less effective in other microbial cell phases. Microbes can more rapidly adapt than human defenses. Microbes benefit from a much quicker generational cycle in all the microbial cell lines compared with humans (Table 1). This further hinders the body’s attempts to battle an established biofilm. Researchers are engaged in a perpetual “arms race” to develop antibiotics to deal with the rapid adaptations and mutations used by microbes. This phenomena has been termed the red queen hypothesis after the scene in Lewis Carroll’s Alice in Wonderland in which no matter how fast Alice and the red queen ran, they were not going anywhere.9

The complex nature of a mature biofilm is confirmed by its ability to self-regulate its biosphere. This is accomplished by an effective method of communicating within the biofilm through chemomodulation (termed quorum sensing). Chemomodulated quorum sensing allows the colony to determine the total population of cells and the distribution of cells between the sessile and persister cell states. This homeostatic state of the biofilm colony

---

Table 1: Generational Cycles of Bacterial Cell Phases Compared With the Human Cycle

<table>
<thead>
<tr>
<th>Organism</th>
<th>Generation Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria (planktonic)</td>
<td>20 to 30 minutes</td>
</tr>
<tr>
<td>Bacteria (sessile, in biofilm)</td>
<td>Hours to 1 day</td>
</tr>
<tr>
<td>Humans</td>
<td>20 to 30 years</td>
</tr>
</tbody>
</table>

---

Figure 1: Illustration of a mature biofilm on an implanted device. (Reproduced from McPherson EJ, Peters CL: Musculoskeletal infection, in Flynn JM, ed: Orthopaedic Knowledge Update 10. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2011, pp 239-258.)

Figure 2: Scanning electron micrograph of a mature biofilm with individual bacteria (round structures) poking through. (Reproduced with permission from Alt V, Lips KS, Henkenbehrens C, et al: A new animal model for implant-related infected non-unions after intramedullary fixation of the tibia in rats with fluorescent in situ hybridization of bacteria in bone infection. Bone 2011;48[5]:1146-1153.)
allows microbes to live in the host. A successful colony will live in peaceful coexistence with the host without destroying it, whereas the colony must prevent its own annihilation by the host’s defenses.

**Managing Bone Defects After Débridement of Osteomyelitis**

After a fracture, instability is indicated by the presence of excessive motion or displaced hardware or the visualization of radiolucencies around screws, rods, or fixator pins. The ability to overcome infection and heal the fracture is compromised by instability; therefore, stability needs to be restored with external or other biologically friendly internal fixation. Bacteria that are attached to surfaces such as metallic fixation devices or dead bone become resistant to the action of antibiotics through the production of a biofilm that forms a protective covering. When unstable hardware is present, it should be removed along with radical débridement of all nonviable bone.

**Staging and Classification**

The Cierny and Mader classification systems are useful for staging chronic osteomyelitis according to the anatomy of the involved bone and physiologic status of the host\(^9\) (Tables 2 and 3). Most patients with posttraumatic osteomyelitis are classified as having

### Table 2

<table>
<thead>
<tr>
<th>Stage</th>
<th>Anatomic Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medullary; no full-thickness involvement of cortex</td>
</tr>
<tr>
<td>2</td>
<td>Superficial involvement of a cortical segment of bone; endosteum is involved, implying intramedullary spread</td>
</tr>
<tr>
<td>3</td>
<td>Full-thickness involvement of a cortical segment of bone; endosteum is involved, implying intramedullary spread</td>
</tr>
<tr>
<td>4</td>
<td>Infection is permissive, involving a segmental portion of bone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Typical Etiology</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infected intramedullary nail</td>
<td>Removal of the infected implant and isolated intramedullary débridement</td>
</tr>
<tr>
<td>Chronic wound, leading to colonization and focal involvement of a superficial area of bone under the wound</td>
<td>Remove layers of infected bone until viable bone is identified</td>
</tr>
<tr>
<td>Direct trauma with resultant devascularization and seeding of the bone</td>
<td>Noninvolved bone is present at same axial level, so the osteomyelitic portion can be excised without compromising skeletal stability</td>
</tr>
<tr>
<td>Major devascularization with colonization of the bone</td>
<td>Resection leads to a segmental or a near-segmental defect, resulting in loss of limb stability</td>
</tr>
</tbody>
</table>


### Table 3

<table>
<thead>
<tr>
<th>Type</th>
<th>Infection Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Normal physiologic responses to infection</td>
</tr>
<tr>
<td>B (local)</td>
<td>Locally active impairment of normal physiologic responses to infection</td>
</tr>
<tr>
<td>B (systemic)</td>
<td>Systemically active impairment of normal physiologic responses to infection</td>
</tr>
<tr>
<td>C</td>
<td>Severe infection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors Perpetuating Osteomyelitis</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little or no systemic or local compromise; minor trauma or surgery to affected part</td>
<td>No contraindications to surgical treatment</td>
</tr>
<tr>
<td>Cellulitis, prior trauma (such as open fracture, compartment syndrome, and free flap), or surgery to area; chronic sinus; free flap</td>
<td>Consider healing potential of soft tissues and bone and anticipate the need for free-tissue transfer and hyperbaric oxygen</td>
</tr>
<tr>
<td>Diabetes, immunosuppression, vascular disease, protein deficiency, or metabolic disease</td>
<td>Consider healing potential of soft tissues and treat correctable metabolic or nutritional abnormalities</td>
</tr>
<tr>
<td>Severe systemic compromise and stressors</td>
<td>Because treatment of condition is worse than the condition itself, suppressive treatment or amputation is recommended</td>
</tr>
</tbody>
</table>

Cierny-Mader stage 3 and 4 disease. A chronic wound infection can lead to stage 2 osteomyelitis. Patients with infected medullary rods or nails and an intact, healed, stable tibia have stage 1 osteomyelitis.

Débridement of stage 3 and 4 osteomyelitis often results in extensive segmental bone defects, which are beyond the healing capacity of the patient. In essence, the surgeon creates an atrophic nonunion, albeit an aseptic nonunion. Multiple reconstructive graft options are available to restore skeletal integrity.

**Cancellous Autograft**

Fresh cancellous autograft provides the quickest and most reliable type of bone graft. Its trabecular structure allows for rapid revascularization (a 5-mm graft may be totally revascularized in 20 to 25 days). Because of the limited quantity of bone available, the use of fresh cancellous autografting may be limited to defects smaller than 6 cm in length; however, success has been reported for defects averaging 10 cm. In general, the maximum amount of graft that can be harvested from a single iliac crest is approximately 30 mL, and the average size defect that can reliably be healed with a single graft is less than 3 cm. Studies document success rates approaching 100% for subcritical-sized defects (1- to 2-cm defects) requiring 20 mL or less of autograft.

The ability to obtain large amounts of autogenous graft material is advantageous for the treatment of critical-sized defects and is therefore a major drawback of iliac autografts. The Reamer Irrigator Aspirator (RIA; Synthes) offers a technique to obtain a substantial amount of graft material for larger defects (Figure 3). The medullary canal of the femur or tibia is reamed with a device designed to collect the reaming material and deliver it for potential grafting procedures. The amount of graft material obtained with this technique ranges from 30 to 90 mL. One study reported a favorable union rate with RIA bone grafting compared with autogenous iliac crest bone grafting, although the difference between the two techniques was not statistically significant.

The RIA harvested material and bone graft harvested from the iliac crest possess similar transcriptional profiles for genes known to act in the early stages of bone formation and repair. The biologic potential of an RIA bone graft has an elevated amount of osteoinductive growth factors and osteoprogenitor/endothelial progenitor cell types relative to an autogenous iliac crest bone graft. This suggests that RIA-generated graft material may be a viable alternative to iliac crest bone grafts when an autologous cancellous graft is needed.
McCall et al. reported on 20 bone defects ranging from 2 to 14.5 cm (average, 6.6 cm) treated using RIA bone graft. Eighteen patients were initially treated with an antibiotic cement spacer (Masquelet technique). The average graft volume obtained with the RIA was 64 mL. Seventeen of the 20 bone defects ultimately healed, although 7 required repeat surgery. Although the early evidence regarding RIA bone grafting is encouraging, high-level comparative evidence is currently lacking.

Masquelet Technique (Membrane-Directed Bone Formation)
The use of antibiotic spacers to develop a well-vascularized pseudomembrane is a precondition to bone grafting critical-sized defects. Masquelet described a two-stage technique for bone defects that involved the formation of an induced membrane around a cement spacer to fill the defect after radical débridement for infection. The spacer is left in place for 6 to 10 weeks to allow for membrane formation and for host to return to an anabolic state. The spacer is removed in the second stage of the procedure and replaced with autogenous iliac crest bone graft (Figures 4, 5, and 6). Systemic antibiotics are generally limited to a short course of days to several weeks, provided that proper débridement was performed. Generally, inflammatory markers are followed to confirm that infection has

**Figure 4** A 40-year-old man with a Gustilo and Anderson type 3A open distal femoral fracture was treated with open reduction and internal fixation. A, Clinical photograph at 3 months postoperatively shows a chronic, draining sinus tract. B, AP radiograph of the fixation hardware shows evidence of loosening and osteolysis that is suggestive of an infected nonunion.

**Figure 5** A, AP intraoperative fluoroscopic view of the femur of the patient in Figure 4 who was treated with staged reconstruction of the infected nonunion required requiring two initial débridement procedures, with removal of all the involved bone and hardware. Because the nonunion was fairly rigid, simple bracing was used between surgeries. B, Intraoperative fluoroscopic view of the bone defect and dead space filled with a large antibiotic spacer and antibiotic beads at the time of definitive wound closure. This required rotation of a local muscle fl ap (vastus lateralis). C, AP radiograph after débridement.
been eradicated. If unsure or if markers remain elevated, débridement is repeated and replacement of the spacer is performed.

Pelissier et al²⁰ reported impressive results after repeated débridements to develop a wound that is healthy and viable. An antibiotic spacer is applied into the defect cavity (off-label use) and the defect is closed, either by primary wound closure or soft-tissue flap procedures. The limb can be stabilized by internal or external fixation. The surgeon makes this determination based on the option that will work best for the particular injury. A tubular pseudomembrane is allowed to develop surrounding the spacer. After wound healing, the antibiotic spacer is carefully removed to preserve the defect cavity and the surrounding membrane. Cancellous autograft is placed directly into the tubularized membrane. Rapid reconstitution of the defect occurs, with improved consolidation times and rates of union compared with historical rates.

Other authors have reported similar union rates when grafting into these membranes with composite grafts, such as DBM plus bone morphogenetic protein (BMP) adjuvants, vascularized free fibula, and RIA-derived grafts.²⁰⁻²⁴ Many of these studies document the addition of culture-specific antibiotics to the cement spacer to facilitate the formation of infection-free membrane-directed bone formation. The improved graft performance is believed to be the result of the ability of the induced membrane to secrete various endogenous growth factors (including vascular endothelial growth factor, tumor growth factor-β1, and BMP-2) and favor the differentiation of human marrow stromal cells into an osteoblastic lineage.

**Figure 6** After 6 weeks of appropriate antibiotic therapy and normalization of the erythrocyte sedimentation rate and the C-reactive protein level, the patient in Figure 4 underwent removal of the antibiotic spacer and beads. A, Intraoperative fluoroscopic view after autogenous bone graft (harvested with a Reamer Irrigator Aspirator) and revision plating (the Masquelet technique). B, AP radiograph taken 9 months after reconstruction shows a healed nonunion that is infection free.

**Osteobiologics and Defect Augmentation**

Concentrated bone marrow aspirate contains a viable population of osteoprogenitor cells that are capable of participating in osteogenesis.²⁵,²⁶ This material has been combined with multiple adjuvants (composites) that serve as osteoconductive carriers to deliver these osteogenic marrow elements. DBM combined with bone marrow aspirate concentrate has been shown to have results comparable with autogenous iliac crest grafts for treating subcritical-sized nonunion defects (typically in the range of 2 to 3 cm). Tiedeman et al²⁵ used bone marrow aspirate concentrate combined with DBM as a composite graft to treat osseous defects of 1 to 2 cm in length. The authors reported a 77% union rate, although the results were less impressive in the subgroup of patients with nonunion (61% union rate).

Hernigou et al²⁵,²⁶ reported excellent rates of union using iliac aspirate concentrates combined with and without DBM for treating nonunion defects up to 3 cm. The quality of the results depended on achieving a threshold number of colony-forming units in the composite graft to attain union in these subcritical-sized defects.

The use of inductive proteins has shown encouraging results for reconstructing segmental defects. Jones et al²⁶ investigated the implantation of BMP-2 combined with allografts compared with autograft for the treatment
of acute segmental tibial diaphyseal bone defects. The average defect size was 4 cm (range, 1 to 7 cm). At 12-month follow-up, 80% of the patients in the group treated with autogenous iliac crest bone grafting and 87% of patients in the group treated with allograft/recombinant human BMP-2 had healed without reintervention. This study suggests that recombinant human BMP-2/allograft is safe and as effective as traditional autogenous bone-grafting for treating extensive traumatic diaphyseal bone loss. Because BMP-2 costs approximately $5,000 per dose, this could limit its use.

Distraction Osteogenesis

There are two strategies for using distraction osteogenesis to treat bone defects. The first strategy involves acute or gradual shortening and compression at the defect site after contouring the bone ends for stability; this process is followed by corticotomy and lengthening at a separate metaphyseal location. Acute shortening can be accomplished safely for defects up to 4 cm in the tibia and the humerus.20-32 Shortening aids in soft-tissue coverage by decreasing tension and gaps in the open wound; this approach combined with negative pressure dressings may allow wounds to be closed by delayed primary closure or healed by secondary intention or simple skin grafting. A frame can be constructed that allows simultaneous compression at the defect site and distraction at a separate location.

A second strategy involves using bone transport to fill the gap, with the normal length of the limb segment maintained (same length as the contralateral limb). The advantage is that the limb can be functional and even bear weight during the process. Bone transport has a high rate of ultimate success, with many series reporting upward of 90% eventually healing with arrest of infection.31,33-35 However, the treatment requires a prolonged period of time (up to 2 months per centimeter of gap filled) in an external fixator. The substantial time required for this technique is the result of delayed healing of the docking site, which frequently requires bone grafting.

The lengthening process can be stopped for patients who experience frame fatigue, which is a psychosis related to the trauma of long-term wearing of an external fixator during a prolonged bone transport procedure. Alternatively, after a stable, healed, shortened limb has been achieved, delayed lengthening can reestablish limb length. Straightforward lengthening now can be accomplished by newer techniques such as rapid lengthening over an internal intramedullary nail; this technique eliminates the need for an external distraction device.36,37

Multiple studies have compared Ilizarov bone transport and conventional techniques for treating bone gaps. In three studies with a total of 101 patients, 48 of the patients were treated with bone transport.32,38,39 The average defect was 5.2 cm for the transport patients and 5.7 cm for patients treated with conventional grafting techniques. The rate of successful healing with the arrest of infection ranged from 71% to 90%; no significant differences were found between the groups. The conventionally treated patients needed more secondary procedures than those treated with bone transport (112 versus 35, respectively). Cierny and Zorn35 reported that those receiving conventional treatment required more transfusions, longer hospitalizations, and more operating room hours than those treated with bone transport. Many of the patients treated with the Ilizarov bone transport technique needed bone grafting for problems at the docking site; however, those bone grafts were much less extensive than the grafts needed in the conventional group.

Soft-Tissue Management for Open Fractures and Infection

Posttraumatic osteomyelitis is a complication of fracture treatment.40,41 Postoperative wound infections requiring bone and soft-tissue débridement can develop in closed fractures treated with open reduction and internal fixation.42 Depending on the status of the soft-tissue envelope, additional soft-tissue procedures may be required to facilitate stable wound closure and dead-space management.33,44 In open fractures, particularly injuries resulting from high-energy mechanisms, adequate soft-tissue débridement is paramount. To emphasize this point, an open fracture is sometimes referred to as a soft-tissue injury that includes a broken bone.

During the past half century, knowledge regarding soft-tissue reconstruction has advanced considerably, particularly since the advent of the operating microscope.45-47 The ability to mobilize composite flaps (defined as tissue transfers that include more than one tissue type, such as a myocutaneous flap) has enabled the trauma surgeon to radically débride any compromised tissue because virtually any defect can be closed using autogenous vascularized tissue transplantation. If wide exposure is required for optimal fracture stabilization or sequestrectomy, the resultant wound can be closed with a variety of techniques if primary closure is not possible.
In addition to advances in soft-tissue closure techniques, the expansion of the armamentarium for bony reconstruction has resulted in a high rate of limb salvage in extremities that may have required amputation in the past. These principles apply to children as well as elderly adults. Although they are important to define, host characteristics rarely interfere with the ability to salvage extremities using an orthoplastic approach in which orthopaedic and plastic surgical skills are combined in a uniform approach to care.

The first principle in wound closure is to ensure adequate wound débridement. This procedure should be performed by a senior member of the trauma team. It is desirable to perform débridement under tourniquet control to avoid blood staining of tissue, which can confound the determination of tissue viability. After débridement, all white structures (bone, tendon, and nerve) should be covered with vascularized tissue. New techniques for débridement include a water-driven soft-tissue cutting tool (Versajet; Smith & Nephew) (Figure 7) that is effective in preserving tissue and indocyanine green tissue labeling (SPY system; Novadaq) that helps in defining tissue perfusion after tourniquet release.

The concept of the reconstructive ladder, originally introduced by Sir Harold Gillies, should be used as a guide to soft-tissue treatment. If primary closure is not possible, skin grafting is possible in the presence of periosteum, paratenon, fascia muscle, or fat. Full-thickness skin grafting is reserved for smaller defects with a well-vascularized wound bed that can accept a thicker graft. Full-thickness grafts rarely play a role in treating large, traumatic soft-tissue injuries. If wound bed optimization is required before skin grafting, dermal substitutes such as INTEGRA (Integra Life Sciences) can be used to optimize local conditions by covering granulation tissue and the neodermis, which enhances acceptance of the skin graft.

Local flaps can include muscle, fascia, or skin. An angiosome is defined as a vascular territory, and perfusion is based on perforating vessels from major arterial conduits. Knowledge of the perforators has led to the expanded use of skin flaps rotated or transposed as “propellers.” Such flaps rely on adequate inflow, which can be assessed in the clinic or operating room with a handheld Doppler device. These flaps are typically used after sequestrectomy to cover scar wounds or sinus tracts after excision. If large defects are created, a free tissue transfer is the ideal solution for the distal third of the leg. The gastrocnemius and soleus muscles are standard lower extremity regional flaps that are often used for the proximal and middle third of the leg after soft-tissue débridement and sequestrectomy. Typically, the muscle flaps are covered with split-thickness skin grafts.

Autologous microvascular tissue transplantation remains the gold standard for defect coverage, dead-space management, and vascularized bone grafting. It can be used in combination with the Ilizarov device in treating osteomyelitis requiring major bone and soft-tissue replacement. Historically, dead-space management emphasized the use of muscle flaps (latissimus dorsi, gracilis, rectus abdominis, or serratus) because of their inherent capillary density compared with free skin flaps (such as a scapular flap). Over time, vascularized skin flaps, such as the anterolateral thigh flap, have been used with excellent results, dispelling the absolute requirement for muscle flaps (Figure 8). The anterolateral thigh flap can be harvested with portions of the rectus femoris if cavitary defects require obliteration.

A variety of choices are now available for conventional bone graft and allograft material. Although the
broadening applications of distraction osteogenesis for bone transport have reduced the need for vascularized bone grafts, large and long defects still benefit from the use of vascularized bone flaps. These flaps can be harvested with skin and even muscle and are particularly valuable in wound beds compromised by scar, vasculopathy, or radiation. The use of a vascularized fibula, with or without skin, should be considered in severe cases or when conventional bone grafting has failed.

Just as there has been an evolution in the reconstructive microsurgery ladder (for example, myocutaneous flaps replaced by perforator flaps), new techniques for vascularized bone grafting have evolved (particularly for small defects). The use of the medial geniculate artery flap has been shown to be effective for recalcitrant nonunions and as a vascularized graft for areas where the fibula’s predominantly cortical bone is difficult to configure (for example, the body of the calcaneus and the talus). The medial geniculate artery flap also can be harvested with skin or muscle as a chimeric flap, with multiple tissues carried on one vascular pedicle (Figure 9).

Discussion
The eradication of musculoskeletal infection requires a treatment plan that addresses the host, the pathogen, the bone, and deficient or inadequate soft tissue. Following a basic algorithm can aid in understanding and maximizing the likelihood of eradicating such infections (Table 4). The orthopaedic surgeon should direct attention to the soft-tissue envelope and then the bone because the soft-tissue envelope can be the limiting factor in attaining successful limb salvage. Working with sound principles and a variety of techniques, limb salvage is possible, and infection can be eliminated.

Summary
Musculoskeletal infections continue to pose a formidable treatment challenge for clinicians. The burden of infection will likely increase in the future because of the occurrence of more traumatic events secondary to urbanization in developing third-world countries. It is imperative for orthopaedic surgeons who treat musculoskeletal infections to
understand how microbes function in the body and how a biofilm is created. Understanding how a biofilm enables microbes to evade eradication helps determine the preferred methods of treatment.

Thoroughly and completely débridement all infected and devitalized tissue and establishing a healthy wound bed are critical in providing a platform for later, staged reconstructions. This approach has led to the most reproducible and good clinical results. Because the long-term use of intravenous antibiotics alone has not been successful in eradicating such infections, proper surgical débridement remains a cornerstone in successfully managing patients with musculoskeletal infections.

References


17. Sagi HC, Young ML, Gerstenfeld L, Einhorn TA, Tornetta P: Qualitative and quantitative differences between bone graft obtained from the medullary canal (with a Reamer/Irrigator/Aspirator) and the iliac crest of the same patient. J Bone Joint Surg Am 2012;94(23):2128-2135.


27. Tiedeman JJ, Garvin KI, Kile TA, Connolly JF: The role of a composite,


